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THE DOLPHIN AIRSHIP WITH UNDULATING DRIVE -- UNDULATORS WITH RIGID OR ELASTIC BLADE WITH DIFFERENT UNDULATOR DIAMETER AT REST AND IN MOTION ON WHIRLING ARM

W. Schmidt

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16. Abstract

Tests were conducted to determine the effect of undulator diameter on thrust for rigid and elastic undulators under different operating regimes. The undulator with rigid blade is less efficient as the diameter becomes smaller in relation to the blade depth. At a diameter of about one-third the depth, it furnishes almost no thrust. For an elastic undulator, thrust is not significantly reduced as diameter becomes smaller.

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Board of Engineering

0. Summary

The undulator with a rigid blade loses efficiency with decreasing undulator diameter in relation to blade depth. When the diameter is about 1/3 of the depth, the rigid undulator with 40% thickness delivers virtually no thrust at all and thus almost no forward motion. /235*

By contrast, the elastic undulator is much more efficient than the rigid one, and almost as efficient at small diameters as at large ones. This is particularly advantageous for the undulator drive of Dolphin airships [1, 2, 3], because it can be designed considerably smaller.

1. Purpose and Scope of Investigation

Results of earlier experiments on undulator propellers [4, 5, 6, 7, 8] suggest that the rotating undulator generates almost no thrust when the undulator diameter is too small. This raises the question of how much the diameter can be decreased, keeping blade depth constant, without appreciably reducing thrust. The form of the blade, whether rigid or elastic, will play an important role -- experiments with the elastic undulator [9] have shown that the thrust of a rigid undulator can be substantially increased by introducing an elastic blade. This raises the further question, of whether the lower limit on rigid undulator diameter also applies to the elastic undulator, or -- as would be expected -- is reduced.

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The present investigation was intended to answer both questions. The two blades studied, the rigid one and the elastic one, are first described. We then report and analyze results of experiments performed on the whirling arm model of the undulator propeller [4, 5, 6, 8, 10]. Lastly, the new information is used to draw conclusions about the Dolphin airship.

2. The Undulator Blades

The rigid blade is 227 mm wide and 125 mm deep, with a so-called circular-nose profile (Fig. 1). It has a thickness of 50 mm, or 40% of the depth, and is mounted on ball bearings near the center of gravity 36 mm from the leading edge of the blade on the crankpin of the whirling arm model. The elastic blade is likewise 227 mm wide, but has a somewhat greater depth of 140 mm. It consists of a rigid nose with a circular-nose profile and a plywood elastic blade 0.4 mm thick, with both external fibers running at right angles to the trailing edge of the blade (Fig. 2). The two blades can be readily installed in succession on the crankpin of the whirling arm model. /236

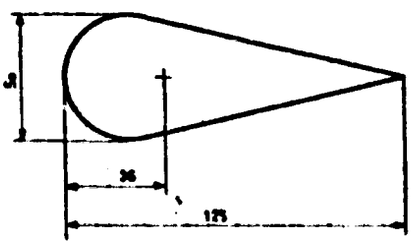

Fig. 1. Profile of rigid undulator blade

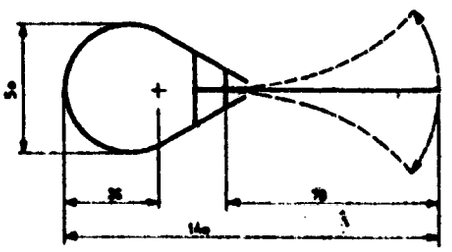

Fig. 2. Profile of elastic undulator blade

The crank radius is designed to be variable. Twice this radius -- called the undulator diameter -- was 4, 6, and 8 cm in the experiments. Fig. 3 shows the rigid blade in four different positions on the undulator circle (4 cm in diameter)

with a compensator behind it in the case of forward motion. The blade is tilted at an angle of -10°; i.e. against the rotation of the undulator. In the case of standing thrust, the compensator is removed and the blade tilted at -40°.

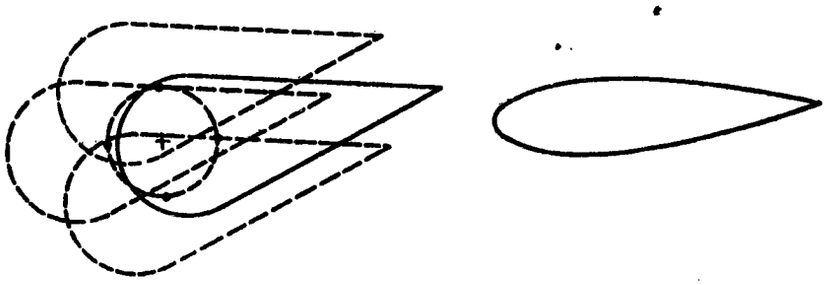

Fig. 3. The rigid undulator in four different positions on the undulating circle 4 cm in diameter, tilted at -10°, with compensator behind it

3. Results and Analysis

Fig. 4 shows the standing thrust S_0 in p [p = gram-force] and the engine power N (in W) calculated from the measured voltage and current strength as functions of undulating frequency n in Hz for both the rigid undulator of Fig. 1 and the elastic undulator of Fig. 2, for each of the three undulator diameters 4, 6, and 8 cm. In the diagram, st = rigid, el = elastic, and the accompanying number indicates the undulator diameter.

When the diameter is 4 cm, the standing thrust of the rigid undulator is very small and hardly changes at all. Evidently, the thrust-generating circulation around the blade is almost completely suppressed by its vigorous circular motion as shown in Fig. 3. Therefore, only a single measurement was made and entered in Fig. 4 (marked st 4). With increasing diameter, the standing thrust increases, as shown by the curves st 6 and st 8. This is also true of the associated engine power.

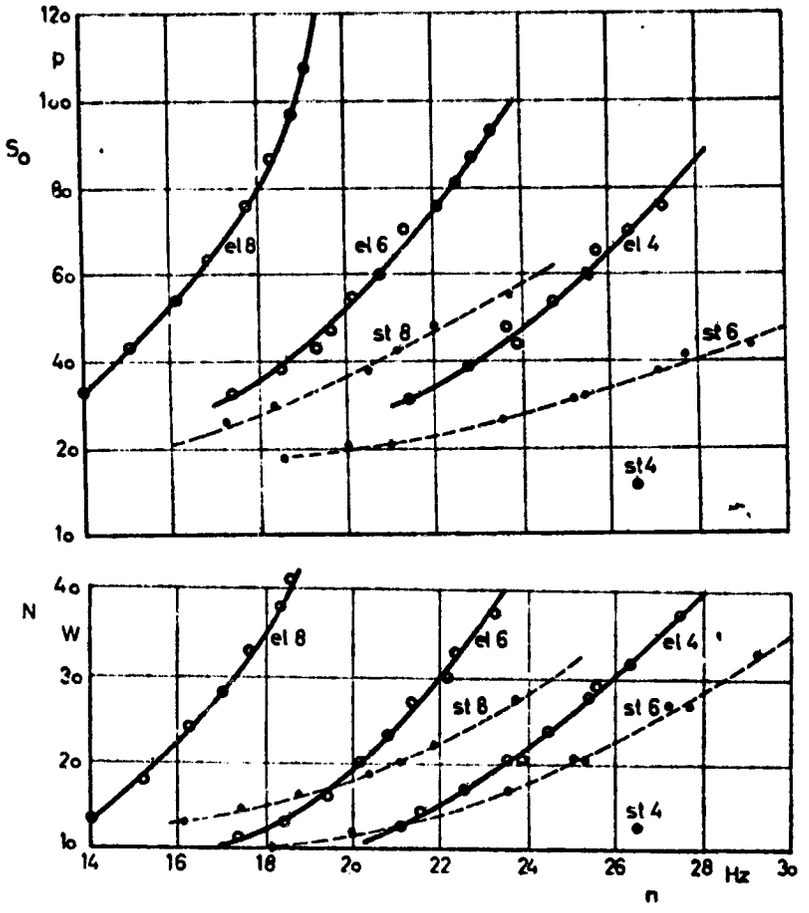

Fig. 4. Standing thrust S_0 in p and engine power N in W as functions of undulating frequency n Hz for rigid and elastic undulators, for each of the undulator diamteters 4, 6, and 8 cm.

The standing thrust of the elastic undulator (el 4, el 6, /237 and el 8) is much greater than that of the rigid one, particularly as the 4 cm diameter. The thrust generating circulation appears to be stronger, and better able to maintain itself against the circular motion. Once again, engine power increases with standing thrust.

For a decision on undulator effectiveness, we need the thrust-power ratio S_0/N shown in Fig. 5. The larger the diameter of its undulating circle, the better the rigid undulator proves

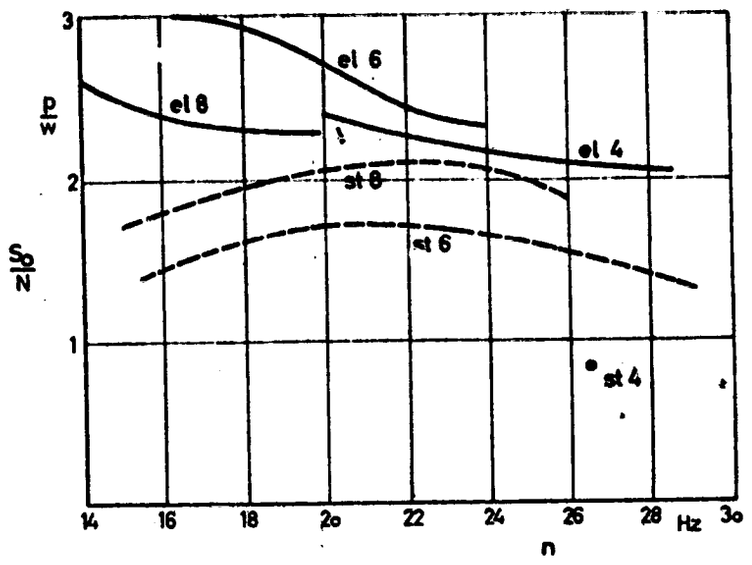

Fig. 5. Thrust-power ratio S_0/N in p/W in relation to undulating frequency n in Hz for the undulators given in Fig. 4.

to be. The elastic undulator is superior to the rigid one, particularly at diameter of just 4 cm. The largest thrust-power ratio is achieved by the elastic undulator with a diameter of 6 cm.

In Fig. 6, the standing thrust is plotted against engine power. The diagram shows that the thrust of the elastic undulator 6 is about 70% greater than that of the rigid one, much as in experiments with the table whirling arm model [9], for which the diameter of the undulating circle was likewise about half the blade depth.

Fig. 7 shows the thrust coefficient k_s, which, as previously [5, 7, 8], was obtained from the equation for thrust

$$S_0 = k_s \, (\gamma/2g) \, u^2 \, F.$$

The coefficient of the elastic undulator is considerably larger than that of the rigid one for all the undulating-circle

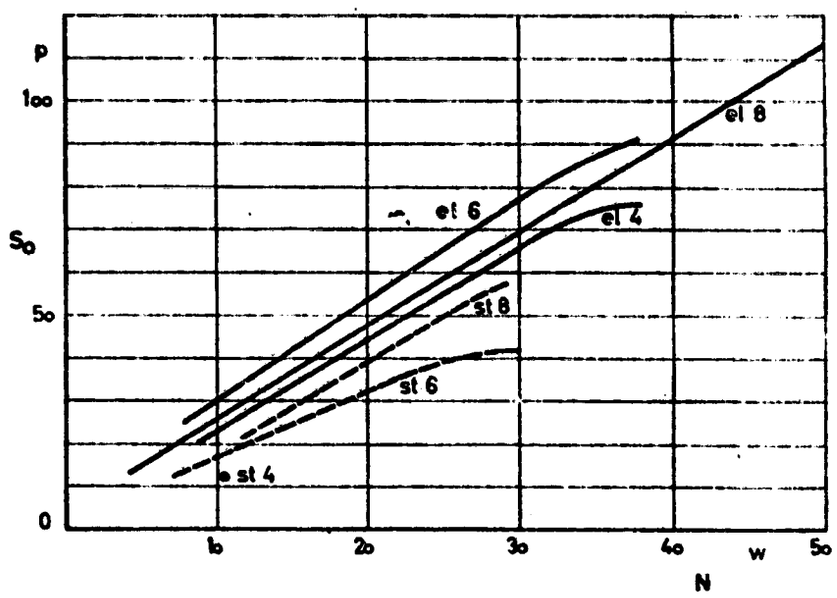

Fig. 6. Standing thrust S_0 in p in relation to engine power N in W for the undulators appearing in Fig. 4.

diameters investigated. For the diameters 6 or 8 cm, it is about three times as great, and for the diameter 4 cm, about six times as great.

An analysis similar to that for the standing undulator can now be carried out for the undulator in motion.

Fig. 8 shows the time T in sec for one revolution of the /238
model on the whirling arm and the associated engine power N in W in relation to undulating frequency n in Hz (for both rigid and elastic undulators) for each of the three diameters 4, 6, and 8 cm.

The rigid undulator with the 4 cm circle moves so slowly that while its engine power N could be plotted as the point

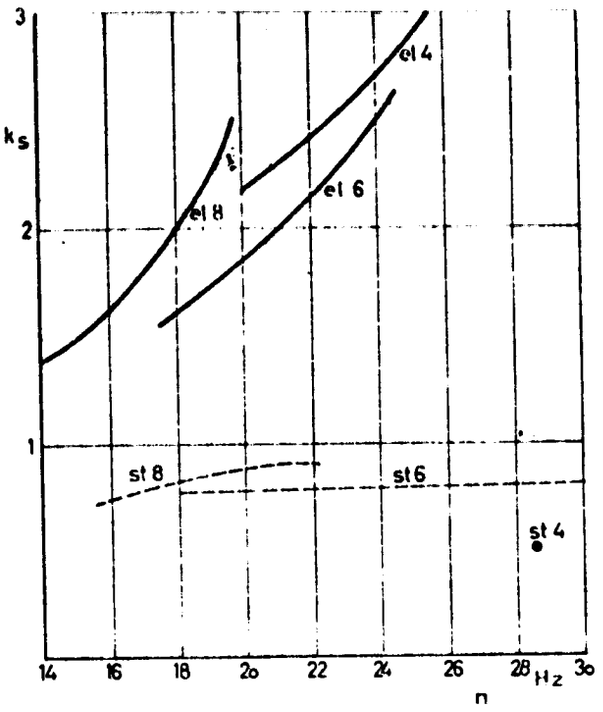

Fig. 7. Thrust coefficient k_s vs. undualting frequency n in Hz for undulators appearing in Fig. 4.

st 4, its extremely long period of revolution could not be. The period of revolution is smallest for the elastic undulator el 8. This undulator is therefore fastest. Accordingly, its merit factor v^3/N [11] (Fig. 9) is also largest, and, according to Fig. 10, more than twice as large for the elastic undulator 6 as for the corresponding rigid one; again a situation similar to that found with the table whirling arm model [9].

Fig. 11 shows the velocity ratio u:v in relation to undulating frequency n in Hz. Here u is the velocity with which the undulator travels around the undulating circle, and v the velcoity of motion of the model on the 1.52 m whirling arm. For the rigid undulator u:v is about 1.7, while the elastic undulator yields much smaller values in the neighborhood of 1.

By comparing Figs. 6 and 10, we observe that the curves associated with the rigid undulator lie further apart; i.e. undulator efficiency decreases sharply with diminishing undulator diameter. Therefore, if a rigid undulator is to be retained, it is advisable to have the undulator diameter no smaller than 2/3 of the blade depth. However, it is much better /239 to adopt the elastic undulator. For the latter, the curves are closer together; in other words, the elastic undulator

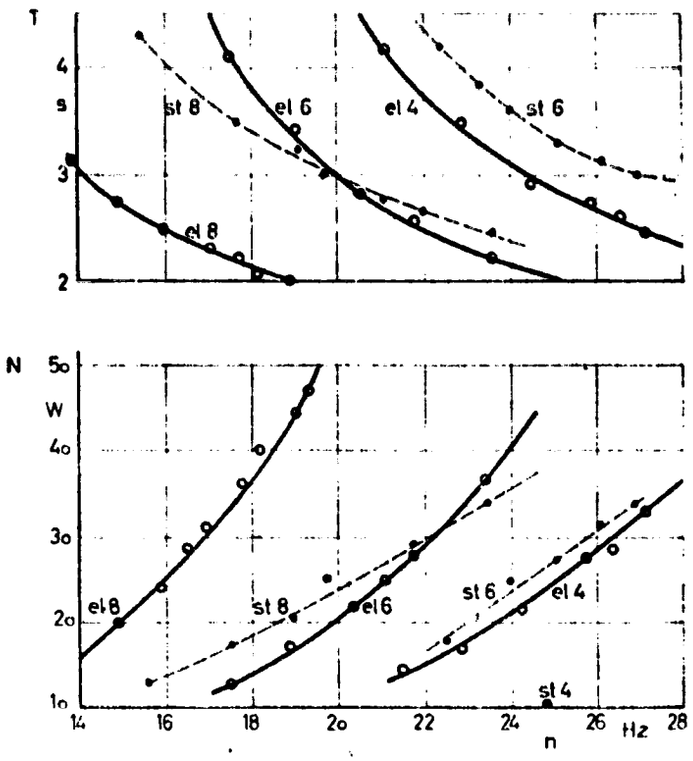

Fig. 8. Period of revolution T in sec and engine power in N in W in relation to undulating frequency n in Hz for the undulators appearing in Fig. 4.

is much less sensitive to undulator diameter. Moreover, the elastic undulator with even the smallest undulating circle studied (4 cm) is still much better than the rigid one with the largest circle (8 cm). Fig. 10 shows that the undulator el 8 is superior to the undulator el 6 in motion, while Fig. 6 shows that the undulator el 8 is surpassed by the undulator el 6 at rest.

4. Consequences for Dolphin airship

Replacement of the previous rigid blade with an elastic one causes a substantial increase in the thrust coefficient (Fig. 7) and simultaneously raises the thrust-power ratio (Figs. 5 and 6), thus making possible a considerable increase in standing thrust with a given undulator size. This is particularly important for the Dolphin airship for lifting heavy loads [12]. Similarly, the merit factor (Fig. 9 and 10) is considerably increased by introducing the elastic blade. A higher speed can thus be obtained with a given engine power. This permits more economical operation of the Dolphin airship. This can also be explained via an increase in the drive efficiency due to a reduction in

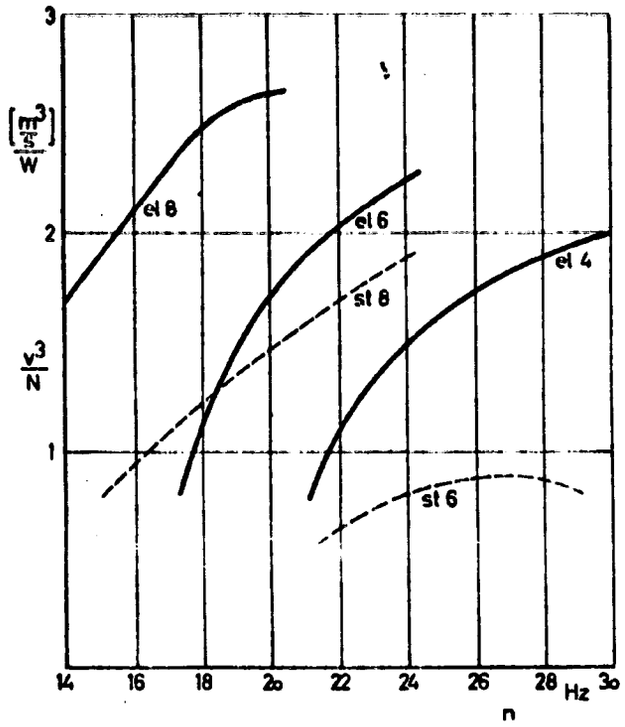

Fig. 9. The cube of velocity of motion v (in m/sec) per engine power N (in W) vs. undulating frequency n in Hz for the undulators appearing in Fig. 4.

u:v brought about by use of the elastic blade (Fig. 11). Compare the efficiency curves of the undulator propeller published in [4, 5, and 6]. /240

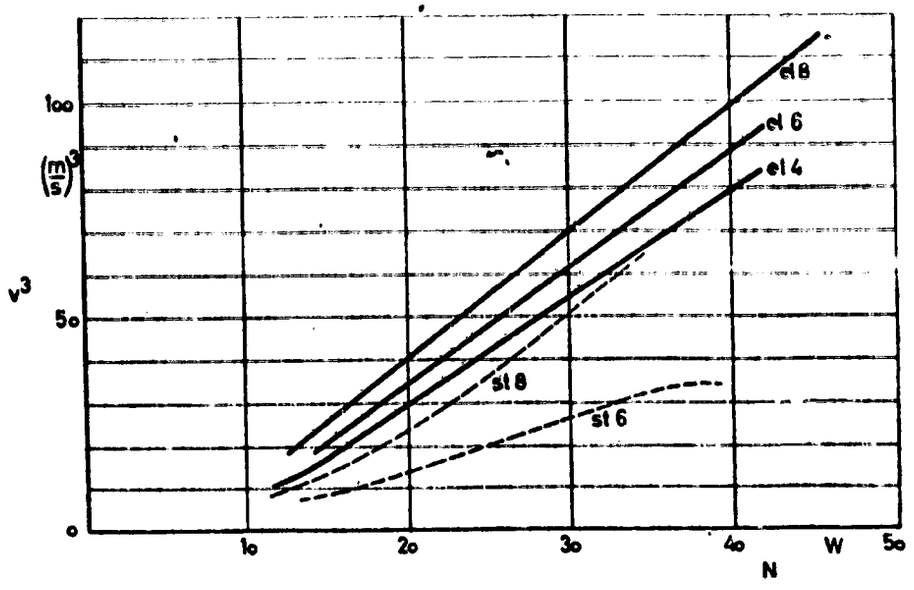

Fig. 10. Cube of velocity of motion v (in m/sec) in relation to engine power N (in W) for the undulators appearing in Fig. 4.

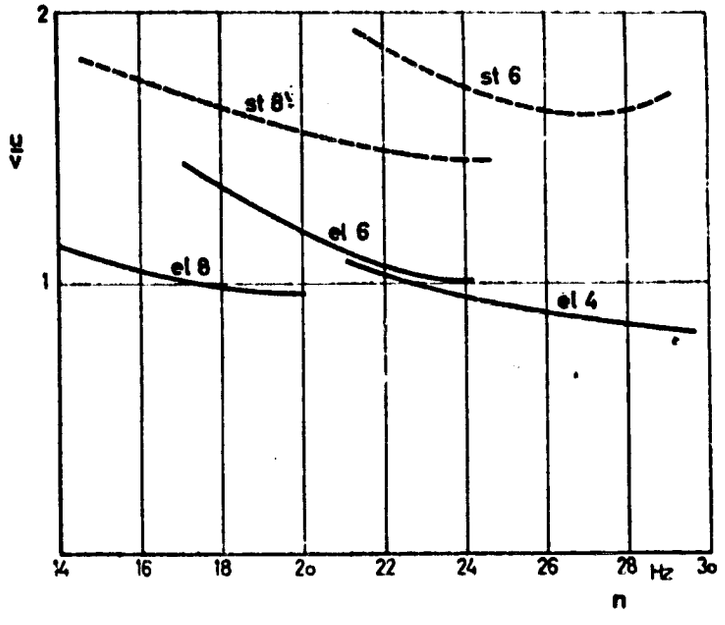

Fig. 11. The ratio of undulator rotation velocity u (in m/sec) to velocity of motion v (in m/sec) vs. undulating frequency n in Hz for the undulators appearing in Fig. 4.

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